Patent Application of

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For

TITLE: PLASTICATING SCREW FOR EFFICIENT MELTING AND MIXING OF POLYMERIC MATERIAL

BACKGROUND - FIELD OF INVENTION

This invention relates to extruders and injection machines of the type in which a screw rotatable within a barrel is employed to extrude or inject molten resinous material to the outlet port of a plasticating barrel. More particularly, this invention is concerned with thorough melting and mixing resinous material at the end of the transition and into the metering section of the plasticating screw.

BACKGROUND DESCRIPTION OF PRIOR ART

Plasticating equipment commonly used today are of the type which receive polymer pellets or powder, heat and work the polymer to convert it into a melted or molten state before delivering the molten polymer under pressure through a restricted outlet or discharge port. Although there are several different types of plastic polymers each having different physical properties, it is desirable that the extrudate leaving the typical plasticating equipment be fully melted, homogeneously mixed and uniform in temperature, viscosity, color and composition.

The plasticating apparatus includes an elongated cylindrical barrel, which may be

through the barrel. The screw has a core with a helical flight thereon and the flight cooperates with the cylindrical inner surface of the barrel to define a helical valley or channel for passage of the resin to the plasticating apparatus outlet port. Although the pitch of the flight can vary it is common to utilize screws of constant pitch. The pitch is the forward distance traversed in one full revolution of the flight. It is also common that screws have a pitch distance that is equal to the outside diameter of said screw. Although there are different screw configurations for different polymer compositions, the typical plasticating screw ordinarily has a plurality of sections along its extended axis with each section being designed for a particular function. Ordinarily, there is a feed section, a transition section and a metering section in series. The plasticating screw feed section extends beneath and forward from a feed opening where a polymer in pellet, powder or regrind form is introduced into the plasticating apparatus to be carried forward along the inside of the barrel. While being carried along said screw axis, the polymer is absorbing heat from said heated cylinder. The depth of said helical flight of the screw in the feed section is usually large enough to overfeed the solid polymer. The overfeeding action serves to compact and pressurize the polymer particles and form a solid bed of advancing material in the plasticating apparatus.

The material is then worked and heated in the transition section so that melting of the polymer occurs as the material is moved forward along said screw axis toward the outlet port. The polymer is passed through the transition section to reduce the root depth of the helical passageway to reflect the volume reduction due to the melting of the feed. The reduction of depth in the transition section also compresses the solid bed of pellets or powder. The transition section leads to a metering section, which has a shallow root depth helical passageway. The preferred geometry moving from the deep feed section to the shallow metering section takes the form of an involute taper geometry. The metering section has as its function the exertion of a constant flow rate pumping action on the molten polymer. In addition, any unmelted solids should be melted in the metering section as well as to mix the melted polymer homogenously. It is understood that a polymer cannot be mixed properly until it is first melted. Generally, when the metering section begins, if the change in flight depth from feed to metering is sufficient and the length of transition sufficient, the resin is at least 90 percent melted.

As previously stated and as described in U.S. Pat. No. 4,752,136, the root depth of the metering section is generally shallow. This shallow depth increases the shear and

the remaining solids to melt. An increase in shear rate and temperature usually has a substantial effect on the viscosity of the polymer. A change in viscosity of the material being plasticated in turn affects the flow rate of the material through the restricted outlet port. As a result, without the optimum screw configuration, there may be a failure to achieve the desired uniformity and output rate of molten polymer, which is a significant problem for the plasticating operation. What makes this task even more difficult is that the current state of the art challenges us with length to pitch and diameter ratios of 12:1 to 27:1. When there is a demand for a high output rate there is frequently not enough axial length to accomplish all that is desired and a compromise in melt quality is experienced.

It is desirous to have a metering section with a shallow flight depth so as to assure that there is a substantial shear rate and good conductive heat transfer from the heated cylinder to the polymer. The most effective melting mechanism takes place between the heated barrel and the polymer. When using the state of the art constant pitch compression screw design that is the most prominent screw in use today, a shallow meter depth can only be accomplished with a high compression ratio between said feed helical channels and said metering helical channel. The practice of increasing the taper to achieve a shallower flight depth in the metering section is proven to be counter-productive because as the taper increases the effective melting length of the screw decreases. In addition, a high compression ratio cannot be used with many polymer types because of excessive shear rates therefore this practice is limited in its scope.

Our invention extends the melting length by utilizing a low volumetric compression ratio. In addition, by increasing the flight pitch of the screw at the end of the transition section as seen in FIG. 2 through 4, the polymer is exposed to more barrel wall surface area and excellent heat transfer. The increase in the flight pitch also increases the velocity between the barrel and the polymer adding a melting and mixing effect. And lastly, by changing the root and the pitch in a un-harmoneous manner as described herein, an added degree of mixing is achieved. So, one skilled in the art would surmise that our invention has created a design that generates a more thoroughly melted and mixed polymeric material without the addition of an expensive, complicated mixing section that is typical of advanced screw designs.

Depending on factors such as the polymer composite, the screw flighted length to diameter ratio, screw diameter and product quality, it is sometimes necessary to add a

possibility and by keeping the metering flight depth shallow for good melting capability and by adding a mixing element within the flow path of the molten material one can obtain a more uniform composition, viscosity, color and temperature of the molten resin leaving the extruder.

Mixing can be defined as a process to reduce the non-uniformity of a composition, resulting in a reduction of the concentration gradients or temperature gradients with the basic mechanism to induce physical motion to the ingredients. Metering sections that comprise a mixing section there-within can be categorized as:

1. Pin Mixers
2. Slotted Flight Mixers
3. Turbine Mixers
4. Variable Channel Depth Mixers
5. Cross-Channel Barrier Mixers
6. Fluted Mixers

Within our reference section, screw designs that have any significance in the industry have been listed. Although I do not believe that there is any prior art that is quite like the present invention, one of our design options shown in FIG. 4, and 4A employs a mixing section that maintains an un-interrupted primary flight for wiping the barrel wall each revolution and maintaining an efficient pumping mechanism. The most closely related mixing screws cited in our references are listed such as #4,178,104. 4,199,263. 3,370,284. 4,173,417. 4,363,768. 4,752,136. 4,639,143. 3,998,438. 4,444,507. and this authors own patent 5,816,698.

To my knowledge there are no designs that make an attempt to increase the flight pitch to achieve a shallower flight depth while maintaining a similar channel volume, nor is there a design that increases the flight pitch whose purpose is to interject a series of intra-flights or a cross-channel barrier flight to add a homogenous mixing effect to the polymeric material while maintaining the same shallow flight depth, in addition there is no relationship between the flight and the root like the present invention employs.

SUMMARY OF THE INVENTION

The present invention is directed to a screw configuration, plasticating apparatus

In accordance with this invention a plasticating screw having a feed section, transition section and a metering section in series, the flight pitch normally being constant in the feed and transition sections, each section having a flight channel forming a specific channel volume when compared with each other forms a compression ratio with the volume of the feed section being greater than that of the metering section. Said screw having at least one but preferably two or more changes in the flight pitch and root diameter at the end of the transition section and through the metering section with the root changing in a un-harmoneous motion with the flight. Said changes that are dependent upon the flighted length to screw diameter ratio, screw diameter and resin composite.

A description of the preferred geometry of the invention follows.

1). The flight depth and pitch of the screw are used to calculate a channel volume. The screw is designed to achieve a given ratio between the channel volumes in the feed section vs. the metering section. At the end of the transition section a tangent point is reached along the axis of the root that represents a flight depth. The flight depth at that tangent point is used to calculate a channel volume. A substantial increase of the flight pitch takes place, the purpose being to achieve a similar channel volume with a shallower flight depth. Said change in the flight pitch should be at least 1.25 x (times) the pitch used through the feed and transition sections and preferably be about between 1.25 and 1.50. An increase in the pitch or helix angle of the flight has the effect to expose a greater amount of polymeric material to the barrel wall as well as to increase the relative velocity between the barrel and the resin. It is well known to those skilled in the art that the most effective melting occurs between the hot barrel and the polymeric material. The resultant shallower than normal flight channel depth has a greater ability to melt the resin completely because of a higher shear rate and more efficient conductive heat transfer even though the volumetric compression ratio remains low which assures a longer axial length of melting ability. The change in velocity has the effect to add a degree of melting and homogenous mixing to the hot resinous material.

2). In our invention, the increase in pitch occurs in conjunction with a change in the root diameter, so as the flight pitch increases, the root of the screw transitions from a deep flight depth to a shallow flight depth, this taper does not occur in a concurrent manner with the flight but in a un-harmoneous manner. The helix angle of the flight that is formed and the angle that is formed by the change in the flight depth do not occur in unison. The change in

about between .7-.9 and 1.1 – 1.3 times farther towards or closer to the point of one complete revolution of the flight.

3). An option that executes two flight pitch increases in succession that are separated by a constant depth metering section, said first flight pitch is about between 1.20 to 1.30 times the original flight pitch, said second flight pitch is about between 1.35 to 1.50 times the original flight pitch. The first change in the root that starts at the same tangent point as the increase in the first pitch ends preferable about between 1.1 to 1.3 times farther towards the point of one complete revolution of the flight, the second change in the root ends preferable about between .7 to .9 times closer to the point of one complete revolution of the flight. It is understood that multiple changes in the flight and root profile while subjecting the resinous material to our substantially shallower metering flight depths are good for melting and mixing.

4). An option that executes a flight pitch increase and root transition as described in item #1 above that is about between 1.25 to 1.5 times the original flight pitch, a second change in the flight pitch that is about between 1.07-1.15 times greater than the previous flight pitch whose purpose is to make room for a single or multiple array of relatively short interrupted helical intra-flight sections and or a un-interrupted cross-channel barrier flight or flights, that are positioned within the boundaries of the primary flight channel while maintaining the same shallow channel flight depth. The relatively short helical flight sections and or cross-channel barrier flights make up a symmetrical pattern that are mathematically similar in width to the differential in channel width created as a result of the flight pitch increase. The introduction of the mixing flight elements is designed to add an exponential amount of mixing to the melt stream while exposing the resin to the continuous shallow flight depth. It is perceived to be an advantage to keep the volume of the first channel similar to the second channel so as not to create a substantial pressure drop. A substantial pressure drop would mean a decrease in material throughput and a loss of revenue.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a plasticating apparatus having a cylindrical barrel and a screw disposed within;

FIG. 1A is an enlarged screw channel cross section

FIG. 2 shows a section of a screw flight profile, end of transition through the metering section, with a single flight and root change;

FIG. 2A is the root profile of FIG. 2;

FIG. 3 shows a section of a screw flight profile, end of transition through the metering section, with a double flight and root change;

FIG. 3A is the root profile of FIG. 3;

FIG. 4 shows a section of a screw flight profile, end of transition through the metering section, with a single flight and root change in addition to a second change in the flight to accommodate a new mixing section.

FIG. 4A is the root profile of FIG. 4;

FIG. 4B is an enlarged view of an intra-flight mixing element of FIG. 4;

FIG. 4C is an enlarged section view of a cross channel barrier flight shown in FIG. 4.

DESCRIPTION OF THE PREFFERED EMBODIMENTS

Referring to FIG. 1, a plasticating screw apparatus can be seen including a cylindrical barrel 12 having a cylindrical inner lining surface. The barrel 12 is provided with a hopper 18 filled with solid resinous material particles and an inlet port 16 for admission of one or more solid particulate resinous materials and any required additives or agents. The barrel is also provided with a discharge port 28 for the discharge of plasticated molten resinous material. Any conventional heating means 14 can be provided on the outside of the barrel 12 for applying heat energy to the barrel 12.

Referring to FIG. 1 and 1A, within the barrel 12 is a screw 10 which is rotated and sometimes reciprocated by means not shown. The screw 10 includes a single helical flight 20 winding around a core 22. The flight includes a flight land 24, which moves in close cooperative association with respect to the inner surface of the barrel 12. The axial distance between comparable points on the adjacent flights represents the pitch of the flight. The helix angle 26 that is formed by the flight in relation to the screw axis is shown in

A flight 20, a core 22, bounded by a flight 20 and the inner surface of the barrel 12 define the flight channel 38. The surface of the core 22 is referred to as the root of the screw. The screw 10 includes a relatively deep root feed section 30 for the admission, heating working and solids conveying of the resinous material, a transition section 32 of reducing depth to adapt to the reduced volume of resin due to the elimination of air spaces between the solid particles, and a relatively shallow metering section 34 wherein the resin is predominantly in a molten state with some amount of solid particles remaining. A discharge port 28 is generally employed at the downstream end of the metering section 34.

FIG. 1A represents an enlarged view of a flight channel 38 while defining the components therein such as the helical flight 20 that is wrapped around a core 22 that forms a helix angle 26 when compared to the flight and axis 74 of the screw 10, the flight 20 being comprised of a leading edge 70 for collecting and advancing resinous material towards the discharge port 28, a trailing edge 72 that forms a boundary for said channel 38 and a flight land 24 that represents the top of the flight and the outside diameter of the screw 10, that works in close proximity with the inner wall of said barrel 12. A flight width 25 which represents the distance between the leading edge 70 and the trailing edge 72 when measured across the flight land 24.

Referring to FIG. 2 and 2A, the basic option of the invention is represented, working from the transition section 32, that tapers from a generally deep feed depth to a shallow metering depth said taper forming a angle 36, advancing along the axis 74 of the screw towards the discharge port 28, a flight pitch 40 that is generally constant with the pitch in the feed section 30, a tangent point between the transition and metering section 44 that signals the start of a change in the flight pitch 42 that is about between 1.35 and 1.50 times the original pitch 40, said tangent point 44 that also forms the starting point for a change in the root 22 of the screw 10 that is not concurrent with the increased pitch 42, said change in the root that is generally about between 1.1 to 1.3 times the length of the increased flight pitch 42 generating a measurable length 46 along the axis 74 that exits at a shallow flight depth 54, shallow flight depth 54 that is constant for the remainder of the metering section 47.

A transition section that is tapered from a deep flight depth to a shallow flight depth that forms a angle 36, a tangent point 44 between the transition section 32 and the metering section 34, that forms a measurable flight depth 45, a channel volume that is

increased flight pitch 42 and similar channel volume that when calculated generates a substantially shallower flight metering depth 54. A flight depth 54 that is substantially shallower than normal and a flight pitch 42 that are substantially longer than normal and a un-harmoneous flight pitch to root transition.

Referring to FIG. 3 and 3A, the generally preferred option of the invention is represented, working from the transition section 32, and advancing along the axis 74 of the screw towards the discharge port 28, a flight pitch 40 that is generally constant with the pitch in the feed section 30, a tangent point between the transition and metering section 44, that signals the start of a change in the flight pitch 42 that is about between 1.20 and 1.25 times the original pitch 40, said tangent point 44 that also forms the starting point for a change in the root 22 of the screw 10 that is not concurrent with the increased pitch 42, said change in the root that is generally about between 1.1 to 1.3 times the length of the increased flight pitch 42 generating a measurable length 46 along the axis 74 that exits at a shallow flight depth 54, shallow flight depth 54 that is constant for a distance 47 that varies depending upon the flight length to screw diameter ratio, and resin composite, a second tangent point 48 that signals another change in the flight pitch 50 that is about between 1.35 to 1.50 times the original pitch 40 said tangent point 48 that also forms the starting point for a change in the root 22 of the screw 10 that is not concurrent with the increased pitch 50, said change in the root that is generally about between .7 to .9 times the length of the increased flight pitch 50 generating a measurable length 52 along the axis 74 that exits at a shallow flight depth 55, shallow flight depth 55 that is constant for the remainder of the metering section 53.

A transition section that is tapered from a deep flight depth to a shallow flight depth, a tangent point 44 between the transition section 32 and the metering section 34, that forms a measurable flight depth 45, a channel volume that is calculated using the original flight pitch 40 and flight depth 45. A design that utilizes two increases in the flight pitch 42 and 50 in succession, separated by a constant depth flight section 47 and two changes in the root 46 and 52 that are not concurrent with the flight pitch, and similar channel volume that when calculated generates a substantially shallower flight metering depth 55. A flight depth 55 that is substantially shallower than normal and a flight pitch 50 that are substantially longer than normal.

Referring to FIG. 4 and 4A, an option of the invention is represented, working from

depth, a flight pitch 40 that is generally constant with the pitch in the feed section 30, a tangent point between the transition and metering section 44 that signals the start of a change in the flight pitch 42 that is about between 1.35 and 1.50 times the original pitch 40, said tangent point 44 that also forms the starting point for a change in the root 22 of the screw 10 that is not concurrent with the increased pitch 42, said change in the root that is generally about between 1.1 to 1.3 times the length of the increased flight pitch 42 generating a measurable length 46 along the axis 74 that exits at a shallow flight depth 54, shallow flight depth 54 that is constant for the remainder of the metering section 47 and 51.

A constant depth metering section 47 that leads to a second tangent point 68 that signals the start of an increased flight pitch 50 and a mixing section. A mixing section that has a increased flight pitch 50 that is about between 1.07 to 1.15 times the prior flight pitch 40 while maintaining a constant depth 54 metering section.

Referring to FIG. 4, 4B and 4C, a mixing section that starts at tangent point 68 that has a increased flight pitch 50 and a constant depth metering flight depth 54, that when calculated makes room for a single or multiple array of relatively short interrupted helical intra-flight sections 56 and or a un-interrupted cross-channel barrier flight or flights 58, that are positioned within the boundaries of the primary flight channel while maintaining the same shallow channel flight depth 54. The relatively short helical flight sections 56 and or cross-channel barrier flights 58 make up a symmetrical pattern that are mathematically similar in width to the differential in channel width created as a result of the flight pitch increase.

The mixing section bounded by length 51, shows three rows of helical intra-flights 56 whose width 60 when multiplied by a factor of three would generally be similar to the differential of the flight pitch between 42 and 50. Another means for calculating the width 60 is to multiply the flight pitch 50 by a factor of about between .025-.04. The length 62 of the helical intra-flight element 56 can be calculated by multiplying the screw diameter by a factor of about between .15-.20. The cross channel barrier flight 58 forms an acute angle 59 with the axis 74 of the screw of about between 15-30 degrees. The flight width 64 is similar to the flight width 60 of the helical intra-flight 56, with the barrier gap 66 being about between .030"-.090". The gap is the distance between the top of the barrier flight 58 and the primary flight land 24 (FIG. 1A). As the molten resinous material advances along the screw channel 38 through the mixing section, it has to pass over the barrier flight 58 and

particles. This restriction is a common practice in the industry and works effectively with some resin composites.

A transition section that is tapered from a deep flight depth to a shallow flight depth, a tangent point 44 between the transition section 32 and the metering section 34, that forms a measurable flight depth 45, a channel volume that is calculated using the original flight pitch 40 and flight depth 45. A design that utilizes a increase in the flight pitch 42, a un-harmoneous change in the root equal to length 46, a constant depth 54 flight section with a length 47, leading to a tangent point 68 that signals a second change in the flight pitch 50 and the start of a mixing element with no change in the flight depth 54. A mixing section that utilizes from time to time an array of interrupted relatively short helical intra-flight elements 56 and from time to time a cross channel barrier flight or flights 58 whose purpose is to assist in the melting process and to add a exponential amount of mixing to the molten resinous material so a more uniform melt pool is obtained. Said addition of a mixing section to be determined by the resin composite and or the screw length to screw diameter ratio.